AMRL-TR-71-74

DEVELOPMENT OF A HUMAN PERFORMANCE RELIABILITY DATA SYSTEM

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JUNE 1971

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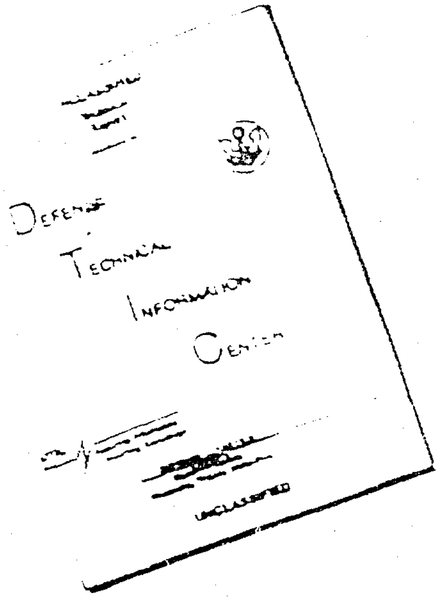

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Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Bunker-Ramo Westlake Village, California	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

DEVELOPMENT OF A HUMAN PERFORMANCE RELIABILITY DATA SYSTEM

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Reprint

5. AUTHOR(S) (First name, middle initial, last name)

David Meister

Robert G. Mills (from Aerospace Medical Research Laboratory)

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1971	15	11

8a. CONTRACT OR GRANT NO. F33615-70-C-1518	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 7184	AMRL-TR-71-74
c. Task No. 718409	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d. Work Unit No. 027	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Presented at the Tenth Reliability and Maintainability Conference June 28-30, 1971	Aerospace Medical Research Laboratory Aerospace Medical Div. AF Systems Command, Wright-Patterson AFB, OH 45433

13. ABSTRACT

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DD FORM 1 NOV 65 1473

Security Classification

NOTICES

Code
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FOREWORD

This report is based on the final report for Contract AF33615-70-C-1518, performed by The Bunker-Ramo Corporation. The research was initiated by the Systems Effectiveness Branch, Human Engineering Division, Aerospace Medical Research Laboratory in support of Project 7184, "Human Performance in Advanced Systems, Task 718409, "Man-Machine Systems Research".

This technical report has been reviewed and is approved.

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DEVELOPMENT OF A HUMAN PERFORMANCE RELIABILITY[1]
DATA SYSTEM

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ABSTRACT

A study was performed to determine the requirements for and the elements of a human performance reliability (HPR) data system. The heart of the HPR system is a taxonomic structure for classifying behavioral studies. 140 studies from a variety of sources were coded using this taxonomy. To test the efficiency of this data bank to provide answers to system development questions a number of tests were performed to determine the relevance of the data retrieved to the questions asked. The results of these tests indicated that it is possible to expand the HPR data base provided one is not restricted to a probabilistic metric.

INTRODUCTION

The primary purpose of this study was to determine the feasibility of expanding the amount of data available for predicting man-machine performance and to develop a methodology for performing that expansion. This study is part of a larger program to develop an HPR system.

We have used the term "human performance reliability" or HPR to denote a metric for the prediction of man-machine performance. In general, that prediction refers to the anticipation of any type of performance effect resulting from the combination of men and machines. One way of conceptualizing man-machine prediction is as the application of performance data in order to human engineer design. In the more traditional and restricted reliability sense, man-machine prediction is the application of probabilistic data to man-machine relationships to establish a quantitative figure of merit, e.g., 9978, for those relationships. We also distinguish between the HPR data system and the data bank which is one element of that system. The term HPR refers to the system, not to the data bank.

Obviously, HPR prediction is only as effective as the body of quantitative data on the basis of which one predicts. Hence the necessity for a substantial data bank. The inadequacies of presently available HPR data banks have been pointed out repeatedly by workers in the HPR fi[illegible]g., Meister, 1964, Swain, 1964, and Altman, 19[illegible] Attempts have been made to remedy the deficiencie[illegible] such efforts as the American Institute for Research (AIR) Data Store (Munger et al, 1962) and by compilations made by Blanchard et al. (1966), Irwin et al. (1964) and Hornyak (1967), but all of these with indifferent success.

An adequate data bank must be both comprehensive (i.e., based on a sufficiently large number of studies) and relevant to system development goals. One might assume that in view of the thousands of behavioral sources in the literature there would be no difficulty in establishing a comprehensive data bank. However, present data banks are not comprehensive, the AIR Data Store (the one most generally used) being based on only 164 studies.

One reason for present data bank deficiencies is that there is a difference between the availability of data sources and the availability of data for use in an HPR data bank. Despite the large number of behavioral data sources, the data they contain are not necessarily relevant to the specialized requirements of HPR. Because of this we distinguish between the general behavioral literature, which may be more or less relevant, and what we call man-machine-specific literature, which one would assume to be highly relevant.

Man-machine relevance is directly related to the degree of similarity between the task characteristics found in potential data sources (the studies) and the characteristics of the tasks employed in operational systems. By task characteristics we refer to: the behavioral functions of the task, the nature of the stimuli and the response equipment, the nature of the individuals performing the tasks and the physical and task environment in which they perform. The more each of these resemble those found in operational systems, the greater the relevance of the study.

Because each of these task characteristics must be considered, it is not enough for the subject matter of the study to appear relevant, for even in this case the data within the study may not be completely relevant; and even if the data are relevant, they may not be in a form which makes them readily usable for HPR purposes.

The task of data bank development is therefore not as simple as it might appear on the surface. Later we shall discuss in detail the special requirements of HPR and the implications these have for the development of an appropriate data bank. For the moment it is enough to say that HPR has two general requirements: to predict the performance of personnel performing in a man-machine context; and to help in the solution of design problems in a manner that will maximize that personnel performance.

Despite the problems that have been cited, it seems reasonable to assume that a large amount of data exists in the general behavioral literature that might be used to expand available HPR data banks. It therefore makes sense to try to extract those data from the literature and to put them into a form usable for HPR prediction.

The study had three phases. In the first phase an examination was made of the kinds of system development questions which an HPR data system should be capable of answering. There would be very little point in developing a system which had only theoretical use by researchers. The first phase also required the development of a methodology which would permit the expansion of the HPR data base. This methodology was conceptualized in terms of a scheme for classifying the behavioral research in HPR terms (i.e., a taxonomy). Phase I concluded with the development of a detailed specification for an HPR data system (what it should consist of).

The second phase involved the application of the

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[1] This paper is based on the final report for contract F33615-70-C-1518, performed for the Human Engineering Division of the Aerospace Medical Research Laboratory by Bunker-Ramo.

taxonomy to studies extracted from the literature to form a preliminary HPR data bank. This data bank was to be purely experimental, to serve as a means of testing the feasibility of the suggested methodology. The development and validation of a comprehensive HPR data bank were manifestly beyond the scope of a single study.

In phase III the preliminary HPR data bank was applied to the solution of a number of system development problems or questions suggested by an actual system development project. The success of this test would indicate how promising the proposed methodology was.

METHOD

Nature of the Problem

To make use of the data in the general behavioral literature, it is necessary to integrate data derived from a variety of studies, each of which used different methods, different equipments and investigated different variables.

The data, whether expressed in the form of error or time or any other measure, pose relatively little problem for the developer of the HPR data system. The difficulty the latter encounters lies in the fact that the study elements in the general literature either do not describe man-machine operations, or do so only in part. If the task elements in the general literature adequately described these man-machine operations, their data could be used fairly readily.

The problem, therefore, becomes one of classifying the elements of behavioral studies in terms such that they agree with the elements describing man-machine relationships. If behavioral task element X is defined as equivalent to man-machine task element Y, data describing the former can be combined with data describing the latter.

It is reasonable to assume that general behavioral and man-machine tasks are related at some higher order level. Obviously the performance of a man-machine task involves some behavioral foundation. For example, to read a meter involves perception, no matter what else it involves. When a subject in a psychological study reads cards as his experimental task, this too involves perception. The problem is, how can we equate reading cards with reading a meter (or reading any display, for that matter)? The stimulus characteristics differ in the two cases and it is reasonable to assume that these characteristics also affect the manner in which the function (reading) is performed. Nevertheless, if one could in some fashion equate the two functions, the data in the behavioral activity could be used to predict the performance of the man-machine activity.

The Problem of Classification

Before we can equate or otherwise relate two or more phenomena, however, they must be classified. The need for a classification system- a human performance taxonomy- has been recognized for years (see, for example, Melton and Briggs, 1960). A number of taxonomies have been developed for varying purposes. Classification systems have been proposed in terms of (1) the behaviors capable of being observed during task performance; (2) the behaviors, functions or processes presumably required during that task performance, but which must be inferred from performance; (3) the abilities the operator must possess in order to accomplish tasks; (4) the characteristics of the task in terms of its stimulus and response properties (eg., complexity, sequence, etc.). At the present time a major 5-year effort is being undertaken by Fleishman and his co-workers (see Chambers, 1969) under ARPA sponsorship to develop a human performance taxonomic system.

Taxonomies differ, however, in accordance with the purpose for which the taxonomy is designed. Previous workers have talked of the taxonomic problem as if there were only one taxonomy, and if that one were developed, it would solve all difficulties. This is not true. There are simply a number of possible taxonomies for different purposes leading to different consequences and outputs. Since the HPR classification structure is directed at the integration of data from widely different sources, it will probably differ materially from other classification systems.

Definition of the HPR Data System

Although this study was directed primarily to the development of a method for expanding the HPR data bank, such a data bank can be thought of meaningfully only as part of an overall data system. It is therefore necessary to specify what that system should consist of.

We use the term "HPR data system" to represent the following:

(1) basic assumptions and goals underlying the system;

(2) definitions of data elements;

(3) a structure for classifying the data elements;

(4) procedures for developing a data bank;

(5) procedures for deriving data from the bank;

(6) procedures for utilizing those data to satisfy system requirements.

In describing the HPR data system it is necessary to examine (a) the functions the system should perform; (b) the system development questions it should answer; (c) the elements that the data system should include; (d) the requirements the system must satisfy. These are described below.

Functions of the HPR Data System

Before developing an HPR system it is necessary to ask what we expect the system to do for its users. To solve the various problems encountered by system developers and the operational users of such systems, the HPR system should possess both design and predictive capabilities. (It should be pointed out that if the only people who were expected to use the system were human factors specialists and reliability engineers, it might be unnecessary to require HPR to have a design capability).

1. Design Capability

   A. Aid in the allocation of functional responsibilities between men and machines, thereby suggesting the manner in which a man-machine configuration should be designed.

   B. Aid in the choice among alternative man-machine configurations and characteristics.

It is assumed that if the system developer knows what human performance can be expected as a function of the manner in which the man-machine configuration is designed, an appropriate choice can be made between alternatives.

Assuming that certain system functions must be performed, the designer conceptualizes various ways in which these functions can be implemented. The HPR data system should be able to indicate the performance expected of the personnel in each alternative. If human performance is insufficient to satisfy system requirements, the function must be implemented by equipment. If human performance in two or more alternative configurations will both satisfy system requirements, then, knowing the anticipated human performance in each configuration, the developer can select the configuration which will produce the more efficient operator performance.

2. Predictive Capability

A. Predict the performance of one or more operators and maintenance men performing a variety of behavioral functions in relation to specified equipment and system configurations; all of this at various levels of system complexity.

B. Indicate the relationship of operator performance to overall system outputs. At any time during system development the developer should be able to predict what the performance of system personnel will be with a given man-machine configuration. He needs to do this for several reasons:

(1) To compare alternative man-machine configurations as in the design capability function described above and to determine which design characteristics need modification;

(2) To compare anticipated human performance with that required by the system to determine where system modifications, if any, must be made;

(3) Where changes in system performance are required, to determine where these changes should be made, i.e., in which system elements, the equipment or personnel.

The HPR data system also implies (even though it may not be stated explicitly) certain measurement characteristics. By specifying the elements that influence per-sonnel performance, the system implies that these are the elements which should be measured or which should be taken into account during the measurement process. For example, the HPR system requires a specification of the characteristics of the stimuli and task performance characteristics found in the measurement situation. Therefore, in any measurement situation which is to be used to provide data for HPR, or whose data are to be compared with a prediction based on HPR, it is necessary to describe these elements. If this is not done, the data gathered cannot be integrated with HPR.

The requirement to aid design solutions and to predict performance levies certain requirements on the HPR data system. In order to aid design the answers supplied by the HPR system must be translatable into design recommendations, i.e., must be usable by designers and developers. This means that performance values supplied by the system must be associated with not only an equipment type (e.g., types of controls and displays or internal components) but also with attributes or dimensions of those equipment types. One must be able to predict performance not only as a function of meters, but also as a function of the scale on the meter, the size of the meter, etc. The designer wishes not only to know which control/display component he should select but also, and even more importantly, the characteristics he should include in that component. This problem has been recognized before; if one looks at the AIR Data Store (Munger et al., 1962), one sees that the performance values have been partitioned among individual equipment characteristics.

Assuming that performance data are associated with individual equipment characteristics, a second problem arises. Equipment is usually selected not on the basis of the individual characteristic, but rather a combination of characteristics. Assuming, purely as a hypothetical example, that characteristic A had an operator performance probability of .96 associated with it and characteristic B a performance probability of .87, what will be the performance probability associated with an equipment which has both characteristics? What is the effect of characteristic A when combined with characteristic B? It is unlikely that the two characteristics are completely independent of each other, which suggests, as Swain (1967) has pointed out, that a simple multiplicative relationship would be too simplistic.

The system configuration the developer is dealing with requires not only the specification of equipment components, but also number and types of manpower, the procedures they should employ in running the system, determination of training content and duration and the specification of work-rest cycles. To choose among alternative man-machine configurations, when these include learning, manpower, etc., means that the HPR system must provide data related to these parameters.

In addition, since the system the developer works with involves not only the single operator interacting with his equipment but groups of operators and equipments, to be maximally efficient, one must supply data relevant to multi-man groups. For the same reason, the prediction one seeks is a prediction of performance of all system personnel functioning to accomplish the system goal; hence HPR must be able to combine individual prediction values to develop a prediction of that goal accomplishment.

Obviously then HPR must supply answers at various levels of interrogation, ranging all the way from component attributes and components to subsystems and systems; and, in terms of the behaviors involved, from task elements (the single switch-throwing activity) all the way through tasks, procedures and finally functions.

The fact that total system output is not necessarily equivalent to the performance of a single operator or a single function/task requires HPR to indicate the relationships to system output of the performance of the single task, the single operator and of all system personnel. The rules for combining performance data from a lower level (e.g., task element) to supply a higher level (e.g., task or function) performance prediction are quite obscure, but HPR must contain them if it is to be effective.

The HPR system developed as the output of the present study obviously cannot contain all the features described above, since considerably more work must be done before problems such as the combination of task predictions and the prediction of group performance can be solved.

System Development Questions HPR Must Answer

Since we assume that HPR exists to supply answers to questions raised during system development, it is necessary to explore these.

1. What is the operator's capability
   a. To perform various functions
   b. Under various task and environmental conditions?

The question is the basic one asked early in system development, when the problem of function allocation arises. Given specific system requirements to be fulfilled, will the operator be able to satisfy these if he is assigned the function? Assume that N messages will be received in a given period of time. If the operator is given the responsibility of receiving these messages, will he be able to do so? Answers to this question will to a great extent determine whether particular functions are allocated to an operator, because if he cannot perform the function, an equipment solution is automatically required.

Obviously the question cannot be answered if we think only of a general function such as message reception. What about message duration? Message format? The manner in which messages must be received (e.g., visually or aurally?). These involve task and environmental conditions which must be linked with the behavioral function to make the functional data meaningful.

It is apparent that no task element in HPR really

has much meaning by itself. If one were to ask, what is the effect of message format on operator performance, the answer would be relatively meaningless unless related to other interactive task characteristics such as message length, mode of presentation, etc.

As a consequence, performance values associated with individual equipment, task or system attributes represent only abstractions from an experimental test. What does it mean when one says that performance as a function of certain scale characteristics is .9873? For convenience we may phrase it that way to permit calculation of that performance effect in interaction with other performance effects of individual characteristics; but what we really mean is that the effect of altering scale characteristics in a particular way is to reduce or alter operator performance on a given task with a given equipment by a certain amount, eg., .0027 or .0018. Change the task or change the equipment with these same scale characteristics and the effect of those characteristics on performance will be .1117 or .00003.

In order to provide a meaningful answer to the user of the HPR system we must therefore associate a data item with as complete a description as possible of the entire task performance context. It also means that that datum is valid only for that performance context. In other words, it is necessary that a given human performance (e.g., .9733 or 5 errors in 100 trials or 19 trials to learn) be associated with all of the task characteristics referred to previously: the behavioral function performed by the human, the nature of the equipment used, the environment, the nature of the stimuli and their characteristics, the characteristics of the subject performing the task, etc. This has major implications for the development of an HPR taxonomy, as we shall see later.

It will be objected that this imposes an inordinately difficult requirement upon the HPR system, because in effect one needs data for an extremely large number of possible combinations of the above task elements. Although this is true, we see no way out of the dilemma. However, it is not supposed that one has to secure all the necessary data at once. Moreover, a considerable amount of data is available that can be used for HPR in its design capacity, even if they cannot be used to develop a quantitative figure of merit.

The point to be remembered is that behavior is not composed of responses to discrete entities like scales, joystick lengths, etc.; these are abstractions; nor can one reconstitute meaningfully homogeneous performance by synthesizing the performance values associated with these abstractions.

All of the preceding suggests that to be optimally efficient HPR must provide data at varying levels of system complexity, varying precision and in terms of varying measures. The particular measure selected is implied by the nature of the function/task performed. It is conceivable that more than one measure can be applied to a particular function. From the standpoint of HPR requirements, it is undesirable that only a single metric be available to HPR. This is particularly true in relation to its design capability. Moreover, that metric must be meaningful to the system developer who uses HPR.

2. What is the effect of various types of equipment characteristics on the operator's performance of specific functions under specific task/environmental conditions?

Assuming that the system developer has decided to assign the responsibility for performing various functions to an operator, his next major step will be to identify appropriate equipment and equipment features to implement the operator function. For example, in a hypothetical Airborne Command Post system it has been decided that certain tactical and strategic messages, e.g., aircraft losses, missiles launched, etc. will be displayed on large screen CRT. Now it is unlikely that the decision to employ a large screen CRT will be strictly a function of operator performance relative to CRTs, but given that such a display is to be used, a host of questions arise: how large must the symbols be to be viewed accurately; what is minimally acceptable resolution; how large should the screen be; the amount of ambient lighting, etc. Note that the answer provided by HPR must be in relation to a specific function performed relative to the CRT, because the performance values one derives from HPR will differ, depending on whether the observer must locate data, or update data, or analyze the displayed information. This forces a relatively high degree of specificity on the user of HPR to phrase his inquiry precisely if he is to receive a precise answer. It also requires of HPR that it supply fairly specific answers to queries if those answers are to be useful.

3. What physical and physiological limitations does the operator impose on equipment design and function/task performance? What environmental factors influence design and performance?

These questions are asked during detail design, in the phase in which equipment characteristics are being developed. It is well known that there are physical (e.g., anthropometric) constraints on equipment that must be taken into account during design. The significance for HPR of this is that if we say that HPR must be responsive to system development questions, it must include a body of data relevant to design even though these data may not be formulated in terms of a performance measure. As a consequence, HPR might include such items as a table of recommended control or display sizes, even though a specific performance equivalent of each control/display size might not be available.

4a. How adequately will the operator perform specific tasks under various task/environmental conditions?

b. How is the performance affected by various equipment characteristics?

This two-part question is an extension of question (1) which dealt with operator capability to perform more general functions. Question (4a) deals with tasks; in the more detailed aspects of design HPR answers phrased in function terms (as they would be for question (1)) would be inadequate.

5. What is the effect of different amounts of manpower on performance of an individual task? Of multiple tasks?

One of the problems the system developer encounters is the requirement to determine the number of personnel needed to perform individual or combinations of tasks. Does a system require a two-man crew or three men? Although the determining factor in solving this problem is the structure of the system and the task, HPR might help in verifying whatever decision (as to crew size) is made. The same man-machine configuration with two different crew sizes could be compared in terms of the performance to be expected with each crew size.

6. How does the performance of one task affect the performance of a second task which occurs either concurrently or sequentially? How is this task performance interrelationship affected by various types of tasks and task conditions?

This description of HPR requirements has until now dealt largely with individual behavioral units (either functions or tasks) but obviously such a limitation severely reduces the usefulness of the HPR system. In order to predict total system performance (the goal of

HPR's predictive capability) it will be necessary to combine task and equipment performance values.

The types of combinations the final HPR system should be able to handle are:

a. multiple equipment characteristics within the same equipment;

b. multiple task elements within the same task;

c. the interaction of equipment and behavioral functions in a single task;

d. the interaction of multiple concurrent and sequential tasks;

e. the interaction of modifying task conditions and single and multiple tasks.

The questions the combinatorial process should be able to answer are:

a. What is the effect of performing two or more tasks concurrently and the resultant performance value?

b. For any series of interrelated behavioral units, what is the performance value to be expected when the series is completed by the operator?

c. What is the relationship between the expected performance of any behavioral unit and the final performance value found in (b) above?

The system developer will find this information useful if, for (a), he is trying to decide whether a given behavioral unit should be performed concurrently or sequentially; for (b), if he wants to determine whether operator performance of the entire system will satisfy system requirements; for (c), if he wants to know whether modifying any single behavioral unit will produce a higher or lower system output.

The establishment of combinatorial rules is the most complex task required in the development of the ultimate HPR system. We do not pretend to have answered this question in the present study.

7. <u>How does the operator's performance vary as a function of repeated trials in: a) learning to perform the task; b) performing the learned task (e.g., fatigue)?</u>

During detail design the developer is faced with the problem of determining how much training should be provided the operator. Training duration is influenced by the highest degree of performance which one can expect as a function of repeated learning trials. The maximum proficiency expected of the operator can also serve as a performance standard which will assist in setting up system requirements.

In many system applications the developer is concerned about the effect of fatigue on performance, particularly in terms of determining an optimal work-rest cycle. Fatigue may be reflected in increasing performance variability, increased errors, etc. Since performance degrades as a function of time, HPR should specify the amount of that degradation that can be expected.

It is apparent that to supply answers to all the questions which one would wish to answer great masses of data must be entered into the HPR system. Manifestly presently available HPR data banks cannot supply these data; hence other sources are needed, which is of course the point of the present study.

<u>HPR System Elements</u>

A review of the system development questions which HPR must answer suggests the elements that HPR must contain. These include:

1. Definitions and taxonomic categorizations of
   a. behaviors;
   b. equipments and equipment characteristics;
   c. stimulus characteristics;
   d. modifying parameters;
   e. response mechanisms and measures;
   f. environmental factors;
   g. personnel characteristics.
2. Performance data describing the items listed in (1) above. This is the HPR data bank.
3. A metric or way of expressing HPR outputs.
4. Rules of operations for
   a. interrogating the HPR data system;
   b. retrieving data from the HPR system;
   c. outputting HPR data;
   d. combining performance values;
   e. extrapolating or generalizing new data from already available data.

<u>HPR System Requirements</u>

The following list describes those requirements which the HPR system must satisfy if it is to provide the functions referred to previously. No particular order of priority is implied.

1. Performance data, in a variety of appropriate metrics, must be capable of being associated with a variety of combinations of man-machine elements.

2. HPR data must be capable of being retrieved for each such man-machine combination. The retrieval process must not be inordinately lengthy.

3. Definitions and categories of the system elements must be in terms that are meaningful to system development users.

4. Entry to the HPR system must be relatively easy and must be capable of being accomplished for each system element and element combination.

5. The system must contain rules for combining performance values to describe total system output. It must possess rules that permit modification of performance values for some system elements by the inclusion of other elements in the behavioral unit, e.g., determining the effect of substandard lighting on performance of a legibility task.

6. The system must accept data from a variety of sources including the general behavioral literature.

7. Ultimately the system should have the capability of generating additional data entries to its store by extrapolating from or otherwise modifying data already within the system.

8. Ultimately the system should have the capability of statistically analyzing its data in response to requests.

9. At least part of the HPR data must be capable of being combined with equipment reliability predictive data.

<u>Alternative HPR Data Bank Formats</u>

A data bank is not simply a data bank, although that impression has developed over the years. It is possible to distinguish five types of banks and two types of users of those banks.

The first type of data bank is what can be termed a <u>probability statement of task performance</u>. A sample item might be: the probability of throwing a double-pole, double-throw switch correctly is .9968. Note that this statement says nothing about the characteristics of that switch, other than its designation, and does not apply a probability statement to those characteristics. Table 1 (taken from Blanchard et al., 1966) reflects such a data bank.

A second type of data bank would consist of <u>probability statements associated with specific equipment characteristics</u>. For example, the probability of

correctly operating a joystick control of stick length 6"-9" is .9963; the probability of correctly operating that joystick with 5-10 lbs. control resistance is .9999, etc. Note that there is no single performance probability associated with the task of joystick operation, only with equipment characteristics, although there is no reason why the two could not be combined. The classic example of such a data bank is the AIR Data Store, several items from which are shown in Table 2.

A third type of data bank could consist of the raw performance values associated with particular parameters. Table 3 presents an illustration of such a data bank format. Note that the data shown in the table are not presented in a probabilistic fashion, although the error data could presumably be transformed into probabilities. Presumably data would be selected to illustrate the desirability of selecting one or the other design characteristic. For example, in the item dealing with TV resolution, it would seem reasonable to the designer that if one wished near perfect observer response, between 7.8 and 13.5 scan lines would be required with symbols 10.2 minutes in size.

A fourth type of data bank could consist of quantitative, non-probabilistic statements related to specific equipment characteristics. For example, a sample item might be: display format X will produce 1.658 times more effective performance than display format Y (X and Y differing in specified ways). The statement can be quantitative or qualitative; could use an arbitrary set of scale values to represent relative performance; or one could use a rating scale or ranking. Table 4 presents a sample set of data bank items of this type.

A fifth type of data bank format and one which is personally most appealing on purely heuristic grounds would combine all the characteristics of the preceding formats. Such a format would provide to the user all the data available in whatever form it could be provided, whether or not the data could be formulated probabilistically. Thus, probabilistic values would be associated with certain tasks and task characteristics, where such values were available; raw performance data for other task parameters would be supplied when probabilistic information could not be supplied. Table 5 presents an illustration of such a data bank item.

The two types of customers who might make use of the various data banks are, besides the human factors specialist, reliability engineers and design engineers. Historically the concept of the HPR data bank was developed out of the reliability engineering tradition which has emphasized prediction- hence the need for probabilistic statements. The design engineer, however, is not so much concerned with prediction as with the selection of one design concept or characteristic rather than another. What this means is that he considers a number of alternative design characteristics and decides that one of these will give him more effective performance. He does not require probabilistic statements because his choices are all relative.

Getting back to the data bank formats, the first type of data bank is not likely to be much use to a design engineer because it does not specify equipment characteristics, which is what he is interested in. Data bank types 1 and 2 differ, moreover, in the ease with which they can be secured. The first type of data can be secured from almost any kind of testing in a non-laboratory environment and requires no special control situation. The second type of data bank can be derived in two ways. It can be derived from the non-laboratory test situation in which the first type was secured, this can be done only if the operator's performance can be partialled out to reflect the individual equipment characteristics he is responding to; or if a sufficient number of different equipments, each one representing a distinct equipment characteristic, can be tested. Then one can develop the second kind of data bank. However, this is very difficult to do in a relatively uncontrolled non-laboratory situation, since the operator responds to the entire equipment, rather than to an isolated equipment characteristic. Moreover, in the operational performance situation the number of distinctly different equipments that can be tested is limited. It appears therefore that it would be difficult to secure the second kind of data bank from non-laboratory testing.

Another way of securing data for the second kind of data bank is from laboratory studies, if the experimenter has specifically set up controlled situations that contrast two or more different equipment characteristics. The experimental situation must therefore be directed at the individual characteristics being compared, rather than at the equipment as a whole. This is precisely what a laboratory situation is designed to do. However, the inadequacies of present data banks reflect the fact that many (if not most) laboratory studies do not contrast all the desired equipment characteristics.

One can use the second type of data bank for design decisions, but the engineer does not make use of the absolute value of the probability statement for this purpose. If one joystick length gives .9968 performance, whereas a second length gives .8968 performance, then the designer implicitly or explicitly ranks the two characteristics (lengths) and selects the one with the higher probability. It would make no difference to the designer if the absolute performance probabilities were different, as long as the two lengths retained their relative performance standing, nor would it make any difference to the designer if the two characteristics were simply ranked 1-2, although he would probably want supporting data to back up the ranking.

Data for the third and fourth types of data banks can be secured from the available results of experimental studies and are moreover easier to develop than either the two previous banks because they do not require that their data be transformed into probabilistic values. Unfortunately much of the general behavioral data cannot be adapted to probabilistic statements because they use such measures as reaction time, response duration, trials to learn, etc.

All things considered, the third and fourth types of data banks are easier for the design engineer to use, they will provide more back-up information, and one can build up a larger data store, because data from the literature that could not be used for the other more restrictive types of data banks could be used for this one.

We do not suggest that one must accept either probabilistic or non-probabilistic data/statements. It is conceivable that both are needed. It is possible that the determination of human capability to perform and the comparison of alternative man-machine configurations in terms of mission requirements will require the traditional kind of probabilistic HPR data. On the other hand, the identification of equipment and the selection of most desirable equipment characteristics will not require probabilistic data but can take advantage of many other kinds of data.

It would seem that a reasonable compromise among the potential data bank formats would be that shown in Table 5. This format takes maximum advantage of all possible data sources and includes all the possible data statements as they become available.

The HPR Taxonomy

The HPR taxonomy shown in Table 6 was developed on the basis of two premises. First, the studies to be classified should be classified in terms of all their relevant parameters. Second, the taxonomy should be an empirical one, based on the variables actually included

in the studies whose data are to be extracted. However, the taxonomy is not open-ended; a category was not added simply because an experimenter decided to investigate it, but because that category was required to answer system development questions phrased in HPR terms.

The taxonomy is not assumed to be complete; if a study is found whose variables cannot be classified according to the taxonomy as it now exists, new categories must be added. The taxonomy is not infinite, of course; as more and more studies are examined, the number of additions to the taxonomy become fewer.

The numbering system in Table 6 is somewhat irregular. The reason for this is that as new categories emerged from examination of the data sources, they were simply added to the preceding categories.

The categories included in the taxonomy are:

A. Perceptual functions (visual scanning).
AB. Auditory perception.
T. Tactile (one study was found that utilized tactile stimulation, and it is conceivable that this sensory mode might be used operationally).
B. Discrete motor tasks (individual, distinct operations).
C. Continuous motor tasks (continuing, integrated sequence of control operations).
D. Cognitive functions (higher-order decision-making operations not subsumed under or required by preceding perceptual/motor operations).
E. Communications functions (person to person communication, either face to face or by instrument).

Each of the above functions may represent a single task or multiples of tasks, depending on the study context. Earlier we had tried to differentiate between molecular and molar tasks and to develop a separate classification for each, but this proved abortive because of the high degree of overlap. This may present a difficulty for the predictive use of HPR, but not for its design use.

F. Visual stimuli, or what is displayed to the subject.
G. Auditory stimuli, or what is presented aurally to the subject.
H. Display equipment, or the sources of stimuli in (F) and (G).
I. Control equipment, or the mechanism used to respond.
J. Subject variables (age, sex, training, experience, etc.).
K. Response measure describing the subject's performance (e.g., error).

Some of the above variables will be found in every study, while others may or not occur in a study depending on the nature of the experimental situation. However, the categories below would definitely not be included in the classification of a study except where they were significant factors influencing that study.

L. Environmental factors, eg., acceleration, temperature, lighting.
M. Stimulus characteristics or distinctive features of the stimuli which could have influenced the subject's performance.
N. Control characteristics or distinctive features of the control equipment which could have influenced the subject.
O. Performance task factors or characteristics of the task situation which either could influence the subject's performance or which describe the manner in which the study was carried out. Finally,
P. Study subject matter, the general theme of the study to permit its more easy retrieval. For example, if one were interested solely in studies of flying performance, such a classification would make it easier to retrieve studies on that subject.

One thing should be immediately clear about this taxonomy. It is purely descriptive, making no assumptions about underlying processes. Consequently, in determining its "validity", the only criterion is its usefulness; one cannot appeal to concepts like "construct validity".

Three processes are involved in the development and use of the HPR data system. These are:

(1) Classification (coding).

a. The classification of the study provided by the HPR developer, i.e., the taxonomic categories assigned to the actual data in the HPR data bank.

b. The classification developed by the user of the system when he asks a question which the system is supposed to answer. The question for which the data system is interrogated must be coded with the same taxonomic categories used to code the original data. The search for a match between these two classifications represents

(2) The retrieval of data from the system.

(3) The combination or integration of the data.

Development of the HPR Data Bank

The incorporation of any data into the HPR system obviously requires first the selection of the studies to be included. The criteria used to select studies were essentially eliminative. That is, all data sources were included except those that used infra-humans (e.g., rats, apes) or children as subjects; or had no usable quantitative data; or in which the subject's responses were primarily physiological, because we cannot tie physiological responses to equipment design; or in which subject responses were those required by formal written tests like intelligence tests; or in which stimuli and task conditions were subjectively oriented like personality studies; or in which it is very difficult to understand what the experimental procedure was; or in which the number of subjects was less than 4.

In general, for a study to be used as source material it had to include some behavior which was credible in a man-machine context, that is, the tasks performed by subjects could conceivably be performed in real life, or bore on some aspect of real life activity. Of course, this involved a certain degree of subjectivity in making choices, but this was unavoidable.

The procedure for coding a study is systematically to go through the list of categories in Table 6, determine which categories apply to the individual study and record the alphanumeric designations of these categories.

Within any major category (A,B,C, etc.) any number of subcategories (1,2,3, etc.) can be applied if they are relevant. This is true even for apparently exclusive categories where a number of conditions have been investigated in the same study. For example, it is possible to have some subjects who are experienced in the experimental task, while others are not. Many of the descriptors for the data in the HPR system contain multiple subcategories, because most of the studies are multivariate in nature.

However, the intent is to record only primary functions and parameters, not merely those that are indicated in the study description simply to supply information. For example, the study report may indicate that viewing distance from a display was 24 inches. However, unless viewing distance was a treatment variable and data were recorded relative to viewing distance, this information would be ignored.

The end product of the classification process is what we call a descriptor, eg., A2/B2/F14/H1/J2/K1/M11/P7, to which is added the index number of the original study

abstract.

The preliminary HPR data bank developed for this study is based on 140 studies, none of which was used in previous data banks. A complete listing of the studies, together with the descriptors for each study, can be found in the final report which served as the basis for this paper.

Use of the HPR Data System

In addition to the classification imposed on the data items in the HPR data bank, the user of the system imposes his own classification by the precision with which he frames a question to be answered by the system. The user may ask a very global question, e.g., what human performance can be expected with displays; or he can frame his question much more precisely, e.g., what is the speed of detecting radar pips on PPI-type display?

The HPR system must be responsive to both types of questions. Of course, the more precise the question, the greater the precision of the information-retrieval and the more relevant are all the studies retrieved.

The system will obviously not accept a question phrased in English. That question must be transformed into taxonomic equivalents. As an example, consider the following question:

How accurately can an operator detect either visual and/or auditory signals over long periods of monitoring?

This is analyzed as follows:

(1) Detection of a visual signal is coded A1.

(2) Detection of an auditory signal is AB1.

(3) No motor, cognitive or communications functions have been specified, so we ignore these. Nor do we have any idea as to the characteristics of the signals, nor of the display equipment.

(4) Accuracy is a rather general measure. Because of its non-specificity, we have to include a number of categories that might apply: K1, 4, 24, 27, 28, 30.

(5) Long periods of time have been specified. This is category O, and subcategories 1, 2, 3, and 4 might apply.

(6) The subject matter of the studies to be retrieved in answer to the question is monitoring/detection, which is category P10.

Consequently the descriptor of the question reads:

A1/AB1/K1,4,24,27,28,30/O1,2,3,4/P10

In attempting to answer the original question, the HPR system operates on the basis of progressive sorting through the various categories to achieve the closest possible match with the entry descriptor (the user's question phrased in terms of the classification categories). Because all studies not meeting the requirements of the entry descriptor are eliminated, the logic employed is "and/or" logic. For example, in the case of an entry descriptor like A2/C3/F14/H1, etc., the system takes up each of the descriptor elements in turn. For example, it might start with A2. Each of the studies in the data bank (or rather its descriptors) would be examined. All studies not having A2 in its descriptors would be eliminated. All the remaining studies (selected because they included A2) would next be examined in terms of the element C3. All studies not having C3 would be eliminated, leaving only studies described by A2/C3. These remaining A2/C3 studies would next be examined in terms of F14, and all studies retrieved by sorting on A2/C3 but not also having F14 would be rejected. This is the essence of the "anding" process.

"Or" logic is represented by the subcategories within each major category, e.g., /K1,2,4/. When this element descriptor is applied to the HPR data bank it means that studies possessing either K1 or K2 or K4 are acceptable.

By this progressive sorting/matching process the precise answer to the question asked can be secured, always assuming that the data bank contains the results of studies corresponding to the entry descriptors. It is of course conceivable that the combination of elements specified in the entry descriptor has no precise counterpart in the data bank. In fact, with a small preliminary data bank such as the one developed for this study, this is often the case. Although one or more studies corresponding to each element in the taxonomy obviously exists in the data bank, the number of element combinations, although not infinite, is very large, and the precise combination desired may not exist. Under these circumstances the user of the system can back off from his entry descriptor and accept a less precise answer; he expands the scope of his question by adding "or" elements.

RESULTS

The usefulness of the HPR system was tested by exercising the system to determine the kinds of answers it could supply to representative system development questions. Only the capability to retrieve relevant data is being tested here. The validity of the data retrieved was not tested.

The method used to exercise the HPR system was:

(1) Develop a number of questions based on problems arising out of actual system development projects, the Titan II Propellant Transfer and Pressurization System (PTPS) and the Bunker-Ramo BR-90 Visual Analysis Console.

(2) Code the questions developed in (1) using the taxonomic categories of Table 6.

(3) Manually sort through the code descriptors of the 140 studies comprising the preliminary HPR data bank until appropriate matches are made.

(4) Examine the data output by the studies retrieved in (3) to determine their relevancy to the question asked in (1).

The efficiency measure utilized is what information-retrieval specialists term a "precision ratio" (Lancaster, 1968). This is defined as 100 x $\frac{R}{L}$, where R is the number of relevant documents retrieved in a search, and L is the total number of documents retrieved in that search. In the case of HPR, if 10 studies are retrieved in a given search, of which 8 are relevant to the inquiry, the precision ratio is 80%.

Relevancy is, unfortunately, a highly subjective measure. For this reason two other staff personnel besides the one conducting the HPR search judged the relevancy of the retrieved studies. Conflicts in judgment were compromised by assigning "partial" relevancy scores.

Moreover, relevancy is not a binary attribute. Rarely does one retrieve studies which unequivocally answer the question asked. In most cases the studies retrieved provide only partial answers to the problem. The following criterion was therefore adopted: a study is relevant if it contains data appropriate to the general subject of the question asked, even though the data do not completely answer the question.

The tests were performed to answer certain methodological questions which derive from the fundamental issues to be resolved with HPR:

(1) Can HPR retrieve data appropriate to the inquiries made of it?

(2) What is the process by means of which appropriate data sources are retrieved?

(3) Can data from the general behavioral literature be integrated with man-machine-specific data?

(4) What degree of precision is required in formulating a question to be asked of HPR?

(5) What is the minimum amount of information with which one must enter the data system to retrieve appropriate data?

Ten (10) test questions were developed based on the PTPS and BR-90 systems. These dealt with such topics as

(a) the loss of performance efficiency one might expect over a 6-8 hour shift;

(b) how rapidly an operator can respond to an emer-

gency situation;

(c) what kind of switch/indicator combination will be most correctly and quickly operated;

(d) what is the maximum number of symbols that should be presented on a small CRT at any one time.

The following test procedure is typical of that used in each test question. The question, what is the minimal size of symbol required to monitor a TV presentation, was coded A1,5/H1/M14,15/P7,10. This was obviously a perceptual function, hence category A was appropriate. Monitoring may involve either detection of the symbol and/or recognition of its meaning. Hence A1,5 to cover both possibilities. It is a TV presentation; hence H1. Symbol size is involved, hence categories M14 or M15 would be appropriate (since we do not know how the symbol size is to be described).

The retrieval process is described by the table. This table has two parts: the categories with which one enters the HPR system, and the studies retrieved as a result of the search.

Entry Categories	Index Nos. of Studies Retrieved
(1) A1,5	1, 5, 11, 12, 13, 16, 17, 18, 20, 22, 24, 26, 27, 28, 29, 31, 33, 35, 36, 37, 38, 43, 44
(2) H1-----> A1, 5[2]	16, 31
(3) M14,15----> H1[3]	16

Study 16 has a descriptor of A5/E4/F13/H1/I7/J3,6,10/K4/M3,14/P3. Study 16 is in fact the study we want because it deals with the identification of symbols on TV as a function of raster scan lines and image size.

The precision ratios produced by each of the 10 test searches are listed below:

Question	Precision Ratio
1	75%
2	66%
3	75%
4	75%
5	75%
6	56%
7	67%
8	50%
9	100%
10	100%

The mean precision ratio is 73.9%.

CONCLUSIONS

The conclusions drawn from the results of the test situations are:

(1) It is possible to expand the HPR data base provided one is not restricted to the traditional probabilistic, reliability oriented metric. The behavioral literature contains considerable data that are useful for HPR's design capability. However, because of the variety of measures employed in the experimental studies, much of these data cannot be transformed into probabilities of accomplishing tasks or partitioned into probabilities for individual equipment characteristics.

(2) Integration of data from the behavioral literature is possible, but not on the basis of statistical combination. The problem with the statistical averaging of data from different data sources is that it may involve combining apples and oranges. Data on accuracy in reading alphanumeric symbols on a CRT gathered in good lighting conditions and in dim lighting will produce distinct differences in accuracy. It is of course possible to ignore the differences in lighting conditions and to average the two sets of results, but the answer received may well be misleading unless the user of the data indicates that he does not care about lighting conditions.

Another way of viewing integration of data is in terms of the application of a common conceptual framework to both general behavioral data and man-machine-specific data. In the context of this study the HPR taxonomy is that common conceptual framework. It is possible to assign relationships in this conceptual structure to a wide variety of studies of different types, thus integrating them.

(3) Our definition of integration emphasizes making data available to the user. From that standpoint the HPR system is not only a data integration system but also an information-retrieval system. From the results of the test searches HPR would seem to be reasonably effective in supplying answers to system development questions.

(4) The system methodology permits an almost infinite number of questions to be asked, limited only by the taxonomic structure so far developed. The system will answer both general and specific questions. The more precisely the question is phrased, however, the more precise the answer retrieved, provided always that the data bank contains relevant data.

(5) It is possible to search the HPR system with only one or two descriptors. Certain descriptors, e.g., M,N,O are more discriminating than others, e.g., J and K. However, all the taxonomic categories are necessary because it is conceivable that a question involvin these categories will be asked. HPR can be entered with alternative descriptors, but in general the same studies will be retrieved regardless of search strategy.

(6) The volume of studies and the number of descriptor elements is such that any practical use of HPR requires computer assistance. However, since the system can be searched with alternative strategies, some of which are more efficient than others, any computer-aided HPR must retain a manual mode and provisions for on-line dialogue between the computer and the user. Since the judgment of relevancy is determined by the user, the user must have the capability of enlarging or reducing his entry descriptors at any time and selecting the data he wishes to inspect.

(7) The process of encoding the user's question requires judgment and practice but is not inordinately difficult. With practice the coding of data to be included in the HPR data bank becomes relatively simple for the great majority of studies abstracted.

We do not pretend that HPR is at the present time more than a concept which not only seems feasible but also has considerable potential not only for the user who is a system developer but also for researchers. Because it organizes the mass of behavioral literature which is highly scattered and diverse, it can permit the researcher to determine exactly what information is or is not available and thus may render the research process more efficient.

Manifestly considerably more work is required if anything practical is to be done with HPR. The taxonomy requires refinement, further testing with a considerably enlarged data base, and possibly reorganization to make it more efficient. The problems involved in computerization of the system need to be explored.

Whether or not HPR development is continued, we can say with some confidence that the HPR data base can be expanded and that it can be made substantially more useful for system developers than it has been so far.

[2] This means that we apply category H1 to all studies retrieved after searching with descriptor A1,5.

[3] This means that we apply descriptor M14,15 to all studies retrieved after searching with descriptor H1.

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TABLE 1. DATA BANK FORMAT I

Stimulus Activity	Probability of Correct Response
1. Turn rotary selector switch and observe CRT signal quality	.9972
2. Observe several dials qualitatively for correct readout	.9973
3. Observe radar scope and mark target position with grease pencil.	.9989
4. Track rapidly moving radar target with 2 unidimensional controls.	.9709

TABLE 2. DATA BANK FORMAT II

JOYSTICK

Reliability	Parameter
	1. Stick length
.9963	a. 6-9"
.9967	b. 12-18"
.9963	c. 21-27"
	2. Extent of stick movement
.9981	a. 5-20 degrees
.9975	b. 30-40 degrees
.9960	c. 40-60 degrees

TABLE 3. DATA BANK FORMAT III

Equipment Type: TV Characteristics	Symbol Size (mins)	Percent Correct Response No. Scan Lines Per Symbol Height			
		4.6	6.3	7.8	13.5
1. No. of raster scan lines per symbol height	4.4	66	76	70	80
2. Symbol subtense angle	6.0	73	91	91	95
	10.2	66	87	97	99

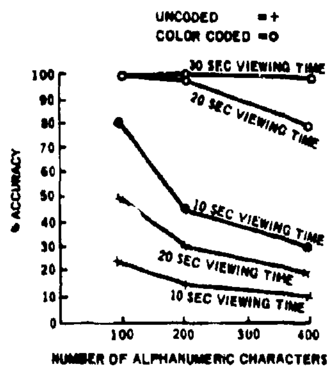
TABLE 4. DATA BANK FORMAT IV

Equipment Type: Large Screen Display

Characteristics	Performance Relationships
1. Vertical vs. horizontal format.	66% more time is spent scanning vertical format than is spent on horizontal array.
2. Effect of coding display.	Mean time to locate coded update information is approximately 65% less than for uncoded updates.
3. Effect of number of stimuli.	Response time increases linearly with number of stimulus elements presented.

TABLE 5. DATA BANK FORMAT V

Equipment Type: CRT Displays

Characteristics	Performance Relationships
1. Probability of correctly performing reading and updating functions.	.9743*
2. With alphanumeric symbols.	.9889*
3. With geometric symbols.	.9654*
4. As a function of resolution:	
6 scan lines	.7543*
8 scan lines	.8644*
10 scan lines	.9044*
12 scan lines	.9756*
5. The effect of density and display exposure time on accuracy.	

6. Improvement in observer performance when displays are coded.

Original Displays	Code Type	Observer Function	% Accuracy Improvement	% Response Time Improvement
Alphanumerics	Color	Locating	44	-----
Alphanumerics	Color	Counting	86	72
Alphanumerics	Size	Update	50	65
Map	Conspicuity (borders)	Information Assimilation/ Extraction	97 and 57	-----

*NOTE: These probabilities are purely hypothetical.

TABLE 6. THE HPR TAXONOMY[4]

FUNCTIONAL BEHAVIORS

A. Perceptual/Visual (scanning displays, physical or natural objects)

1. To detect or verify the appearance of stimuli.
2. To note or detect the movement of stimuli.
3. To detect a change in stimuli.
4. To detect a change in stimulus characteristics.
5. To identify/categorize/recognize stimuli in terms of known data.
6. To compare stimulus characteristics.
7. To identify stimuli that deviate from standards or other stimuli.
8. To locate the position of stimuli or objects in terms of a standard.
9. To change the position of stimuli.
10. To change the characteristics of stimuli by motor action.
11. To count or calculate stimuli.
12. To introduce/input new stimuli by motor action.
13. To delete or remove stimuli (reverse of (12)).
14. To read where reading is the sole function involved.

AB. Auditory Perception

1. To detect or verify the appearance of stimuli.
2. To detect the movement of stimuli.

3-4. Deleted

5. To identify/categorize/recognize stimuli in terms of known data.
6. To compare the characteristics of auditory stimuli.
7. To identify stimuli deviating from standards or other stimuli.
8. To detect a change in the stimulus.
9. Deleted.
10. To change the characteristics of auditory stimuli by motor action.
11. To count or calculate stimuli.

T. Tactile Perception

1. To detect the occurrence of a tactile sensation.

B. Discrete Motor Behaviors

1. To activate controls to positions without displayed information.
2. To activate controls to positions in accordance with or as a result of displayed information.

3-4. Deleted

5. To connect or disconnect objects either directly or with tools.
6. To carry objects.
7. To open/close door or enclosure.
8. To mark position of objects.
9. Deleted.
10. To aim at an object.
11. To lift object.
12. To drop object.

C. Continuous Motor Behaviors

1. To adjust position of objects without reference to displayed information.
2. To adjust position of objects in accordance with or as a result of displayed information.
3. To adjust position of controls to change the position of moving stimulus.
4. To record information manually.
5. To input data by activating controls.
6. To input data manually.
7. To walk from one point to another.
8. To swim from one point to another.
9. To run from one point to another.
10. To throw an object.
11. To exert hand grip.
12. To remove objects from or install them in designated positions.
13. To file objects.

D. Cognitive Behaviors

1. To perform quantitative computations.
2. To compare calculated values.
3. To decide between two or more hypotheses.
4. To analyze information.
5. To hypothesize causal relationships.
6. To verify that an hypothesis is correct or incorrect.
7. To code/decode stimuli.
8. To predict the occurrence of an event.
9. To recall/remember stimuli/events (short term, long term).
10. To estimate the occurrence or characteristics of phenomena.
11. To note a change in displayed information.

E. Communications

1. To request instructions/information using a device.
2. To request instructions/information face to face.
3. To communicate instructions/information over device.
4. To communicate instructions/information face to face.
5. To listen to information supplied by device.
6. To listen to information supplied face to face.

F. Visual Stimuli

0. Stimulus not specified.
1. Alphabetic characters, static.
2. Alphabetic characters, moving.
3. Numeric characters, static.
4. Numeric groups, static.
5. Numeric groups, moving.
6. Alphabetic words, static.
7. Alphabetic words, moving.
8. Numeric characters, moving.
9. Alphanumeric groups, static.
10. Alphanumeric groups, moving.
11. Unstructured, static.
12. Unstructured, moving.
13. Coded (geometric symbol), static.
14. Coded (geometric symbol), moving.
15. Coded, color.
16. Natural object.
17. Photograph of natural object.
18. Written statements.
19. Environmental (sky, land, water).
20. Deleted.
21. Pointer deflections.

[4] This is an abbreviated version of the original taxonomy. Detailed definitions and examples will be found in the final report of this study referred to earlier.

TABLE 6. THE HPR TAXONOMY - (Continued)

22. Grid map.
23. Oscillograph trace.
24. Terrain map.
25. Paper chart trace.
26. Graph.

G. Auditory Stimuli

1. Tones varying in frequency.
2. Tones varying in loudness.
   2A. Tone sequences.
   2B. Interruption of tone.
3. Complex sounds varying in frequency.
4. Complex sounds varying in loudness.
5. Words.
6. Numbers.
7. Letter sequences.

H. Display Equipment

1. CRT (TV type).
2. CRT, PPI type, standard.
3. CRT, PPI type, non-standard.
4. Card, drawing or other paper presentation.
5. Projected display, static.
   5A. Projected display, dynamic.
6. Large screen display.
7. Film.
8. Sound recording.
9. Natural object.
   9A. Physical object not resembling natural objects.
10. Indicator, steady state.
11. Indicator, blinking.
12. Deleted.
13. Visual track, dynamic.
14. Still photograph.
15. Internal component.
16. Display panel, non-cockpit.
17. Cockpit instruments.
18. Legend light.
19. Scale indicator, meter.
20. Scale indicator, circular or curved.
21. Scale indicator, horizontal straight.
22. Scale indicator, vertical straight.
23. Scale indicator, fixed pointer, moving scale.
24. Counter, direct reading.
25. Printer.
26. Plot board.
27. Matrix board.
28. Person to person speech.
29. Loudspeaker.
30. Bell, buzzer or horn.
31. Oscillograph.
32. Switch setting.
33. Tachistoscope.
34. Paper tape recorder.
35. Moving belt containing stimuli.
36. Earphones.
37. Electro-pulse stimulator.

I. Control Equipment

1. Discrete control, single, e.g., switch.
2. Discrete control, multiple, e.g. keyboard.
   2A. Chord keyboard.
3. Continuous rotary control, single, e.g., dial, knob.
   3A. Continuous rotary control, multiple, eg., "ganged" knobs.
4. Thumbwheel.
5. Continuous linear control, single, e.g., lever, joystick.
   5A. Sidearm controller.
   5B. Center controller.
   5C. Displacement control.
   5D. Pressure control.
6. Track ball.
7. Verbal response.
8. Written response.
9. Control panel.
10. Walking.
11. Running.
12. Swimming.
13. Microphone.
14. Steering wheel.
15. Throwing.
16. Aircraft simulator.
17. Dynamometer.
18. Nuts/bolts.
19. Sextant.
20. Punch device.
21. Pencil.
22. Typewriter.
23. Lightpen.
24. Electro-mechanical manipulator.
25. Push-pull device.
26. D-ring.
27. Handtools.
28. Moving table.

J. Subject Variables

1. Unknown.
2. Civilian student (both men and women).
3. Civilian non-student (also men only).
4. Military personnel, undifferentiated.
   4A. Military student.
   4B. Military reservist.
5. Previous task experience, unspecified.
   5A. Novice.
   5B. Somewhat experienced.
   5C. Highly experienced.
6. No previous task experience.
7. Diver.
8. Under 30.
9. Over 30.
10. Pilot.
11. Seaman.
12. Maintenance
13. Clerical.
14. Technical.
15. Shop.
16. Inspector.
17. Women.
18. Police.

K. Response Measure

1. Error, number of.
2. Response duration.
3. Reaction time.
4. Accuracy.
5. Trials to criterion.
6. Response variability.
7. Time to criterion or time to learn.
8. Number of subjects reaching criterion.
9. Distance travelled.
10. Trials to learn.
11. Target acquisition time.
12. Omissions, number of.
13. Errors and omissions combined.
14. Velocity.
15. Inch/ounces, torque.

TABLE 6. THE HPR TAXONOMY - (Continued)

16. Force (lbs.).
17. Number/percent false reports (detection).
18. Angle, degrees/seconds of arc.
19. Illumination measure.
20. Magnitude estimation.
21. Recognition threshold.
22. Time on/off target.
23. Response probability.
24. Number/percent detections.
25. Percent/rank preference.
26. Confidence in response.
27. Percent errors.
28. Percent accuracy.
29. Trials in error.
30. Strokes per second or operation.
31. Percent omissions.
32. Range at which stimuli are recognized.
33. Point of subjective equality.
34. Body dimensions.
35. Correlation values.
36. Stimulus coding.
37. Type of verbal material.
38. TV camera field of view.
    38A. Shades of gray.
39. Slant range to target.
40. Scale orientation.
41. Display advanced or delayed.
42. Number of stimulus channels.
43. Number of levels of information per channel.
44. Rate of display change.
45. Number of stimuli to be detected.
46. Stimulus flash rate.
47. Type font.
48. Stimulus aperture size.
49. Stimulus distance travelled.
50. Stimulus presentation speed.
51. Stimulus clustering.
52. Intersensory stimulus combinations.
53. Distance separating stimuli.

L. Environmental Factors

1. Temperature.
2. Noise.
3. Lighting.
4. Vibration.
5. Acceleration.
6. Underwater.
7. Sound intensity.
8. Wind speed.
9. Air speed.
10. Night.
11. Day.

M. Significant Stimulus Characteristics

1. Stimuli grouped.
2. Stimuli ungrouped.
3. Stimulus resolution.
4. Stimulus brightness.
5. Stimulus intensity.
6. Stimulus duration, momentary.
7. Stimulus duration, intermediate.
8. Stimulus duration, prolonged.
9. Stimulus similarity, physical.
10. Stimulus similarity, analog.
11. Number of stimulus.
    11A. Frequency of stimulus presentation.
12. Stimulus location.
13. Stimulus viewing angle.
14. Stimulus size, angle subtended.
15. Stimulus size, physical dimensions.
16. Speed of stimulus movement.
17. Scale graduations.
18. Monaural auditory stimuli.
19. Binaural auditory stimuli.
20. Stimulus mode of presentation.
21. Preadptation.
22. Stimulus color/color contrast.
23. Display format vertical.
24. Display format horizontal.
25. Display format variable.
26. Display spacing/location.
27. Amount of information.
28. Amount information change.
29. Stimulus brightness contrast.
30. Figure/ground relationship.
31. Deleted.
32. Stimulus static, unmoving.
33. Stimulus moving.
34. Large/group display.
35. Small/individual display.

N. Significant Control Characteristics

1. Number of controls.
2. Location of controls in front of operator.
3. Location of controls to side of operator.
4. Control operated with ungloved hands.
5. Controls operated with gloved hands.
6. Arrangement of controls varied.
7. Control size.
8. Spacing between controls.
9. Number of parts in internal component.
10. Control-display relationship compatible.
11. Control-display relationship incompatible.
12. Type of vehicle being controlled.
13. Control panel size.
14. Control panel markings.
15. Manipulator characteristics.
16. Control friction.
17. Control inertia.
18. Control position relative to body.
19. Direction of control movement.
20. Control force.

O. Performance Task Factors

1. Performance over successive trials.
2. Performance over successive hours.
3. Performance over successive days.
4. Performance over successive shifts.
5. Performance in terms of time of day.
6. Feedback presented.
7. Feedback not presented.
8. Type of feedback.
9. Amount of feedback.
10. Feedback delay amount.
11. Stimulus viewing distance close.
12. Stimulus viewing distance remote.
13. Performance within moving vehicle/simulator.
14. Deleted.
15. Distance travelled by operator.
16. Direction of movement by operator.
17. Defect rate (inspection).
    17A. Defect type.
18. Number of responses controlled by instructions.
19. Speed of responses controlled by instructions
20. Tracking in 1 dimension.
21. Tracking in 2 dimensions.
    21A. Tracking in 3 dimensions.
22. Pursuit tracking.
    22A. Tracking control break point.
    22B. Tracking control dead zone.
    22C. Target step function.

TABLE 6. THE HPR TAXONOMY - (Continued)

22B. Target ramp function.

23. Compensatory tracking.
    - 23A. Target step function.
    - 23B. Target ramp function.
24. Deleted.
25. Performance incentive provided.
26. Aircraft emergency tasks.
27. Aerodynamic flight equations.
28. Message load.
29. Message type.
30. Job aids.
31. Computer-aided instruction.
32. Subject handedness.
33. Tracking dynamics.
34. Task cueing.
35. Secondary task.
36. Target importance varied.
37. Missing data.

P. <u>Study Subject Matter</u>

1. Transfer of training.
2. Training/practice.
3. Threshold determination.
4. Code translation.
5. Driving performance.
6. Tracking.
7. Controls/displays.
8. Physical capability, e.g., anthropometry.
9. Flying.
10. Monitoring/detection.
11. Motor capability.
12. Mental capability.
13. Target identification.
14. Inspection.
15. Information transmission.
16. Command/control.
17. Stimulus legibility.
18. Work load.
19. Filing.

*U.S. Government Printing Office: 1971 — 759-077/056